Vicus

TECHNOLOGIES, LLC

Final Report

"Development of Zinc Sulfide Seeker Window Material"
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Submitted by:
Vicus Technologies LLC
86 York Street
Kennebunk, Maine 04043

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1.0 **Introduction**

This report presents the thermophysical property data measured on Zinc Sulfide seeker window material. The overall objective of this research and development effort is to establish an alternate seeker window material as contrasting to the currently used THAAD sapphire window and validate the predictions for an alternate seeker window material, multispectral zinc sulfide, by conducting thermal and structural testing of ZnS coupons. Vicus Technologies LLC has teamed with Lockheed Martin Space Company to evaluate and validate the capability of multispectral zinc sulfide seeker window material.

The use of zinc sulfide as a replacement window for the current sapphire offers significant increase in waveband and reduced costs for the final interceptor window (70%-80%. reduction as compared to sapphire). Zinc sulfide is currently available from a number of manufacturers and the selected material for this evaluation was Cleartran®, a product of Rohm & Haas. Cleartran is a multispectral version of zinc sulfide where Hot-Isostatic Pressing is used to post-process the material which increases its waveband by removing porosity from the material.

An alternate seeker window for current interceptor constructs would improve the acquisition range of current seeker systems and improve target discrimination. Future interceptors may use dual color focal planes. Seeker window materials represent an integral part of an advanced seeker system. These windows must be capable of meeting the severe thermal environment and structural loads imparted on the window during target acquisition and end-game maneuvers. Advanced seeker window materials must satisfy thermo structural requirements and demonstrate improved optical performance.

Based on computational fluid dynamics analysis and 3D finite element thermal and structural analysis that has been conducted on worst case mission environments, zinc sulfide is a window material candidate that is predicted to exceed requirements. This is also supported by a statistical strength model for zinc sulfide based on limited flexural strength coupon data which also considered size effects. These initial analysis and reference test data provide validation for additional development. The proposed effort involves thermophysical property and optical property testing at room and elevated temperature levels to support the analytical predictions and establish the validity of multispectral zinc sulfide as a candidate window material. Based on positive results, the follow on efforts will address optical property testing of Anti-Reflective (AR) coated ZnS followed by full-scale AR ZnS window thermostructural testing under the same conditions as the current THAAD window was verified, e.g. Hypervelocity Wind Tunnel Testing to demonstrate that zinc sulfide meets the performance requirements.

Two primary efforts were conducted under this effort. The first was thermal property testing of uncoated ZnS coupons. These materials were procured by Lockheed Martin under internal development funding to provide single lot coupons for both their internal development effort and for conducting the thermophysical property testing. The purchase of the test coupons under a single source insured lot consistency and tracking of the test specimens. The uncoated ZnS specimens were purchased as a single lot and were machined and polished to THAAD specifications.

The material was procured from Rohm & Haas as bulk material and subsequently supplied to Pacific Optical for coupons machining and finishing to current window specifications. In order to detect any lot-to-lot variation in the material, half the test coupons were obtained from one lot and half from a separate lot. In this approach, coupons were removed from separate CVD and HIP runs and each plate was labeled with a unique serial number and coupon position with regard to orientation of the plate. Witness coupons were removed and archived for each plate to indicate their “as-received” state. The archived specimens will be used for microstructure evaluation. A coupon was archived from both the “as grown” (e.g. CVD’d) and after HIP’ing. The coupons for thermal testing were ground with an 80/50 surface finish. The test coupons for thermal conductivity testing were machined and ground to nominally 0.5 inch diameter by 0.1 inch thick. Thermal expansion specimens were machined and ground to 2.0” long by 0.25 inch square and specific heat coupons were 0.23 inch diameter by 0.04 inch thick.

The optical test specimens were prepared under the same requirements as the thermal test material. The specimens were all marked with a control number on their circumference. The specimens were nominally 1.5inch diameter by o.2 inch think.

Listed below in Table 1 is a summary of the specimens which were received. Note that these specimens do not have an AR coating.

The thermal testing was conducted at the Thermophysical Properties Research Laboratory, Inc, (TPRL) at Purdue University. Thermal expansion testing was conducted using a quartz dilatometer. Specific heat was determined with a scanning calorimeter and thermal conductivity measured using flash laser diffusivity. Three (3) test replicates were measured for each test. The details of the tests are discussed in section 2.0.

Optical testing consisted of measuring the Reflectance (R), Transmission (T), and Emittance (E). R, T, and E was measured normal to the surface of the test coupon using two (2) different techniques. Using a sphere technique, the R, T, and E was measured at room temperature (e.g. 25°C) and 200°C. Using a goniometer/cryostat technique, these same optical properties were measured at 25°C and 250°C. The two techniques were used to evaluate any difference in the results. Two replicates were used for each test.

Table 1 – Summary of Uncoated ZnS Test Coupons

Test Designation	**Identification No.**	**Dimensions (inches)**
Specific Heat	S/N 27-01	0.230 diameter x 0.0416 thick
Specific Heat	S/N 27-02	0.230 diameter x 0.0427 thick
Specific Heat	S/N 49-01	0.230 diameter x 0.0420 thick
Specific Heat	S/N 49-02	0.230 diameter x 0.0418 thick (spare coupon)
Thermal Expansion	S/N 27-01	2.010 x 0.2540 x 0.2532
Thermal Expansion	S/N 27-02	2.011 x 0.2541 x 0.2531
Thermal Expansion	S/N49-01	2.005 x 0.2541 x 0.2534
Thermal Expansion	S/N 49-02	2.005 x 0.2542 x 0.2537 (spare coupon)
Thermal Conductivity	S/N 27-01	0.500 diameter x 0.1055 thick
Thermal Conductivity	S/N 27-02	0.500 diameter x 0.1055 thick
Thermal Conductivity	S/N 49-01	0.500 diameter x 0.1055 thick
Thermal Conductivity	S/N 49-02	0.500 diameter x 0.1050 thick (spare coupon)
R,T,E Optical	S/N 27-01	1.496 diameter x 0.1992 thick
R,T,E Optical	S/N 49-01	1.495 diameter x 0.1996 thick

Where: R = Reflectance
T = Transmission
E = Emittance

Transmission properties were also measured at 16, 30, 45, and 60 degrees for a spectrum of 3-11 microns. Measurement at 45° and 16° was measured using the sphere technique where transmission at 45° was measured at room temperature only and at an incidence angle of 16°, it was measured at room temperature and 200°C. Using the cryostat, 16, 30, 45 and 60 degrees were measured at room temperature and 200°C. It should be noted that the temperatures selected represent near the maximum temperatures predicted for the seeker window under worst case flight conditions. Consequentially, these temperature levels also represent the maximum operating temperatures of the test equipment.

2.0 **Test Results**

Thermophysical properties were measured at TPRL. The bulk density of the coupons was determined from the mass and geometry of the coupons. The thermal diffusivity was measured using the laser flash techniques and specific heat was measured using a differential scanning calorimeter. The thermal conductivity was calculated as a product of these measured quantities e.g. $k = \alpha C_p d$.

The laser flash diffusivity method is described in ASTM E1461. In summary, the front face of the sample coupon is subjected to a short laser burst and the resulting rise in the rear face temperature is recorded. Since the ZnS material is transparent to the laser wavelength a thin coating of opaque material was applied to the front face of the coupon. The apparatus used consisted of a Korad K2 laser, a high vacuum system utilizing a bell jar with viewing ports, a tantalum/stainless tube heater which surrounded the sample holder assembly, an IR detector, and the accompanying electronics. A microcomputer controls the test, collects the data, calculates the results and compares the data to a theoretical model.

Specific heat was measured with a Perkin-Elmer Model DSC-2 Differential Scanning Calorimeter. Sapphire was used as a reference material. The ZnS sample and the reference are subjected to equal heat flux and the difference in the power to heat the samples and standard at equal rates were determined and data recorded using a digital data acquisition system. Using the mass of the reference and the ZnS coupon, the differential power required to heat the samples, and the known specific heat of sapphire, the specific heat of the ZnS was calculated. All measured values are traceable to NBS standards.

For thermal expansion, a dual push-rod dilatometer (Theta Dilatronics II) was used and the test was conducted following ASTM Standard E228. The differential expansion between a known sample and the ZnS material was measured as a function of temperature. The test was conducted under computer control and the linear expansion of the sample was measured at pre-selected temperature intervals. The reference material was selected (six each were available) based on the expected expansion of the ZnS and all the reference materials were traceable to NBS. The thermal expansion was measured with a graphics terminal. The mean coefficient of thermal expansion at a temperature was determined by calculating the change of length of the sample in accordance with the following relationship;

$$\alpha_{mean} = (L_T - L_o)/L_0 \div (T - T_o)$$

Where: T_o is the reference temperature of 20°C

The bulk density results for the diffusivity samples are shown in Table 2.

Table 2 – Sample Dimensions, Mass and Specific Gravity Values

Sample No.	Thickness (cm)	Diameter (cm)	Mass (gms)	Specific Gravity (gm/cc)
27-01	0.2686	1.2711	1.365	4.005
27-02	0.2687	1.2714	1.374	4.030
49-01	0.2679	1.2705	1.369	4.032

Results of the specific heat testing are listed in Table 3. The experimental uncertainty of the measurements is ± 3%.

Table 3 – Tabulated Results of Specific Heat Measurements

Temperature (C)	**27-01 (W-s/gm-K)**	**27-02 (W-s/gm-K)**	**49-01 (W-s/gm-K)**
-60	0.4545	0.4510	0.4522
-50	0.4574	0.4580	0.4551
-40	0.4609	0.4600	0.4580
-30	0.4644	0.4640	0.4640
-20	0.4673	0.4680	0.4673
-10	0.4714	0.4710	0.4714
0	0.4743	0.4740	0.4754
10	0.4783	0.4760	0.4789
23	0.4800	0.4810	0.4820
50	0.4880	0.4890	0.4910
75	0.4950	0.4950	0.4990
100	0.5020	0.5050	0.5060
125	0.5080	0.5110	0.5120
150	0.5120	0/5150	0.5160
175	0.5160	0.5180	0.5190
200	0.5180	0.5200	0.5220
225	0.5200	0.5220	0.5230

250	0.5220	0.5250	0.5250
275	0.5230	0.5260	0.5260
300	0.5240	0.5270	0.5270
325	0.5260	0.5280	0.5280
350	0.5270	0.5290	0.5290
370	0.5280	0.5300	0.5290

Results of the thermal diffusivity tests are tabulated in Table 4. It should be noted that a thin coating of opaque (e.g. black) paint was applied to the surface of the specimens to prevent laser beam penetration during the test. The diffusivity values were found to be within an experimental uncertainty of ± 3%.

Table 4 – Thermal Diffusivity Test Results

Temperature (°C)	**Sample 27-01 ($cm^2\ sec^{-1}$)**	**Sample 27-02 ($cm^2\ sec^{-1}$)**	**Sample 49-01 ($cm^2\ sec^{-1}$)**
-40.0	0.1870	0.1880	0.1920
-20.0	0.1720	0.1730	0.1770
23.0	0.1440	0.1460	0.1470
50.0	0.1295	0.1310	0.1310
100.0	0.1059	0.1075	0.1056
200.0	0.0736	0.0727	0.0702
300.0	0.0501	0.0508	0.0502
370.0	0.0408	0.0422	0.0412

Table 5 illustrates the tabulated values for the calculated thermal conductivity. Total experimental uncertainty of the thermal conductivity determination is ± 6%. The thermal conductivity values for all three samples result in a narrow band and are within the uncertainty of the thermal conductivity determination.

Table 5 – Thermal Conductivity Calculations of Multispectral Zinc Sulfide

Sample Number	Temp. (°C)	Specific Gravity (gm/cc)	Specific Heat (w-s-gm^{-1}K^{-1})	Diffusivity (cm^2 sec^{-1})	Thermal Conductivity (W-cm^{-1}K^{-1})	Thermal Conductivity (BTU in hr^{-1}ft^{2}F^{-1})
27-01	-40	4.005	0.4609	0.1870	0.3452	239.51
	-20	4.005	0.4673	0.1720	0.3220	223.35
	23	4.005	0.4800	0.1440	0.2768	192.08
	50	4.005	0.4880	0.1295	0.2531	175.63
	100	4.005	0.5020	0.1059	0.2129	147.73
	200	4.005	0.5180	0.0736	0.1527	105.96
	300	4.005	0.5240	0.0501	0.1051	72.94
	370	4.005	0.5280	0.0408	0.0863	59.89
27-02	-40	4.030	0.4600	0.1880	0.3485	241.79
	-20	4.030	0.4680	0.1730	0.3263	226.37
	23	4.030	0.4810	0.1460	0.2830	196.35
	50	4.030	0.4890	0.1310	0.2581	179.10
	100	4.030	0.5050	0.1075	0.2188	151.80
	200	4.030	0.5200	0.0727	0.1523	105.65
	300	4.030	0.5270	0.0508	0.1078	74.79
	370	4.030	0.5300	0.0422	0.0902	62.55
49-01	-40	4.032	0.4580	0.1920	0.3546	246.01
	-20	4.032	0.4673	0.1770	0.3335	231.39
	23	4.032	0.4820	0.1470	0.2857	198.22
	50	4.032	0.4910	0.1310	0.2594	179.95
	100	4.032	0.5060	0.1056	0.2154	149.47
	200	4.032	0.5220	0.0702	0.1478	102.55
	300	4.032	0.5270	0.0502	0.1067	74.01
	370	4.032	0.5290	0.0412	0.0879	61.02

Table 6 shows the tabulated thermal expansion results. The samples were first tested at below room temperature and the temperature increased to 400 C. The number of data points taken during cooling was less as shown below. The samples were slightly shorter after testing as shown in the data and subsequent plots.

Table 6 – Tabulated Thermal Expansion data

	Temp (C)	$(L-L_0)/L_0$		Temp (C)	$(L-L_0)/L_0$		Temp (C)	$(L-L_0)/L_0$
27-01 H	-60	-0.000456	**27-01 C**	400	0.002915			
	-50	-0.000406		390	0.002832			
	-40	-0.000353		380	0.002747			
	-30	-0.000299		370	0.002663			
	-20	-0.000242		360	0.002580			
	-10	-0.000183		350	0.002497			
	0	-0.000123		340	0.002414			
	10	-0.000060		330	0.002331			
	20	0.000006		320	0.002248			
	30	0.000070		310	0.002167			
	40	0.000138		300	0.002086			
	50	0.000206		290	0.002004			
	60	0.000275		280	0.001923			
	70	0.000345		270	0.001843			
	80	0.000416		260	0.001764			
	90	0.000488		250	0.001684			
	100	0.000560		240	0.001604			
	110	0.000632		230	0.001524			
	120	0.000705		220	0.001432			
	130	0.000778		210	0.001351			
	140	0.000851		200	0.001271			
	150	0.000925		190	0.001191			
	160	0.000999		180	0.001113			
	170	0.001074		170	0.001037			
	180	0.001149		160	0.000963			
	190	0.001224		150	0.000887			
	200	0.001301		140	0.000813			
	210	0.001378		130	0.000739			
	220	0.001455		120	0.000667			
	230	0.001533		110	0.000598			
	240	0.001612		100	0.000527			
	250	0.001691		23	-0.000100			
	260	0.001771						
	270	0.001852						
	280	0.001933						
	290	0.002014						
	300	0.002095						
	310	0.002177						
27-01H	320	0.002259	**27-02 H**	-60	-0.000451	**27-02 C**	400	0.002967
	330	0.002341		-50	-0.000403		390	0.002881
	340	0.002423		-40	-0.000350		380	0.002795

H = Heating Cycle
C = Cooling Cycle

350	0.002504
360	0.002586
370	0.002668
380	0.002750
390	0.002832
400	0.002917

-30	-0.000296
-20	-0.000239
-10	-0.000180
0	-0.000119
10	-0.000056
20	0.000009
30	0.000074
40	0.000140
50	0.000209
60	0.000278
70	0.000348
80	0.000420
90	0.000492
100	0.000565
110	0.000638
120	0.000713
130	0.000788
140	0.000863
150	0.000940
160	0.001016
170	0.001094
180	0.001171
190	0.001249
200	0.001328
210	0.001407
220	0.001486
230	0.001566
240	0.001646
250	0.001726
260	0.001807
270	0.001888
280	0.001970
290	0.002052
300	0.002134
310	0.002216
320	0.002298
330	0.002381
340	0.002464
350	0.002547
360	0.002631
370	0.002714
380	0.002798
390	0.002881
400	0.002966

370	0.002710
360	0.002626
350	0.002542
340	0.002459
330	0.002375
320	0.002292
310	0.002209
300	0.002127
290	0.002044
280	0.001961
270	0.001880
260	0.001799
250	0.001718
240	0.001636
230	0.001554
220	0.001472
210	0.001391
200	0.001311
190	0.001232
180	0.001152
170	0.001075
160	0.000999
150	0.000920
140	0.000842
130	0.000760
120	0.000683
110	0.000609
100	0.000541
23	-0.000050

	Temp (C)	$(L-L_0)/L_0$
49-01 H	-60	-0.000456
	-50	-0.000408
	-40	-0.000355
	-30	-0.000301

	Temp (C)	$(L-L_0)/L_0$
49-01 C	400	0.002918
	390	0.002833
	380	0.002749
	370	0.002665

-20	-0.000243	360	0.002582
-10	-0.000184	350	0.002499
0	-0.000123	340	0.002417
10	-0.000060	330	0.002334
20	0.000006	320	0.002252
30	0.000071	310	0.002171
40	0.000138	300	0.002090
50	0.000206	290	0.002008
60	0.000275	280	0.001927
70	0.000345	270	0.001847
80	0.000416	260	0.001767
90	0.000488	250	0.001687
100	0.000560	240	0.001607
110	0.000632	230	0.001527
120	0.000705	220	0.001432
130	0.000779	210	0.001351
140	0.000853	200	0.001270
150	0.000927	190	0.001189
160	0.001002	180	0.001111
170	0.001077	170	0.001036
180	0.001152	160	0.000960
190	0.001228	150	0.000886
200	0.001304	140	0.000811
210	0.001380	130	0.000737
220	0.001457	120	0.000665
230	0.001535	110	0.000596
240	0.001612	100	0.000526
250	0.001691	23	-0.000075
260	0.001770		
270	0.001849		
280	0.001929		
290	0.002009		
300	0.002090		
310	0.002172		
320	0.002254		
330	0.002336		
340	0.002419		
350	0.002502		
360	0.002585		
370	0.002668		
380	0.002751		
390	0.002834		
400	0.002918		

The mean coefficient of thermal expansion is tabulated in Table 7.

Table 7 – Mean CTE for Multispectral Zinc Sulfide

Temperature	MEAN CTE		
	27-01	27-02	49-01
Degrees C	micro in/in C	micro in/in C	micro in/in C
-60.0	5.69	5.64	5.70
-50.0	5.78	5.74	5.81
-40.0	5.87	5.82	5.91
-30.0	5.95	5.89	5.99
70.0	6.94	6.99	6.93
80.0	6.96	7.02	6.96
90.0	6.99	7.04	6.99
100.0	7.01	7.08	7.01
110.0	7.04	7.11	7.04
120.0	7.06	7.14	7.07
130.0	7.08	7.17	7.09
140.0	7.11	7.21	7.12
150.0	7.13	7.24	7.14
160.0	7.15	7.27	7.17
170.0	7.17	7.30	7.19
180.0	7.19	7.33	7.21
190.0	7.21	7.36	7.23
200.0	7.23	7.39	7.25
210.0	7.26	7.41	7.27
220.0	7.28	7.44	7.29
230.0	7.31	7.46	7.31
240.0	7.33	7.49	7.34
250.0	7.36	7.51	7.36
260.0	7.39	7.54	7.38
270.0	7.41	7.56	7.40
280.0	7.44	7.58	7.42
290.0	7.46	7.60	7.45
300.0	7.49	7.63	7.47
310.0	7.51	7.65	7.49
320.0	7.54	7.67	7.52
330.0	7.56	7.69	7.54
340.0	7.58	7.71	7.56
350.0	7.59	7.72	7.59
360.0	7.61	7.74	7.61
370.0	7.63	7.76	7.63
380.0	7.64	7.78	7.65
390.0	7.66	7.79	7.66
400.0	7.68	7.81	7.68

As stated previously, the thermophysical property measurements were conducted at TPRL. Pictures of the facilities used to conduct the tests are shown in Figures 1-3.

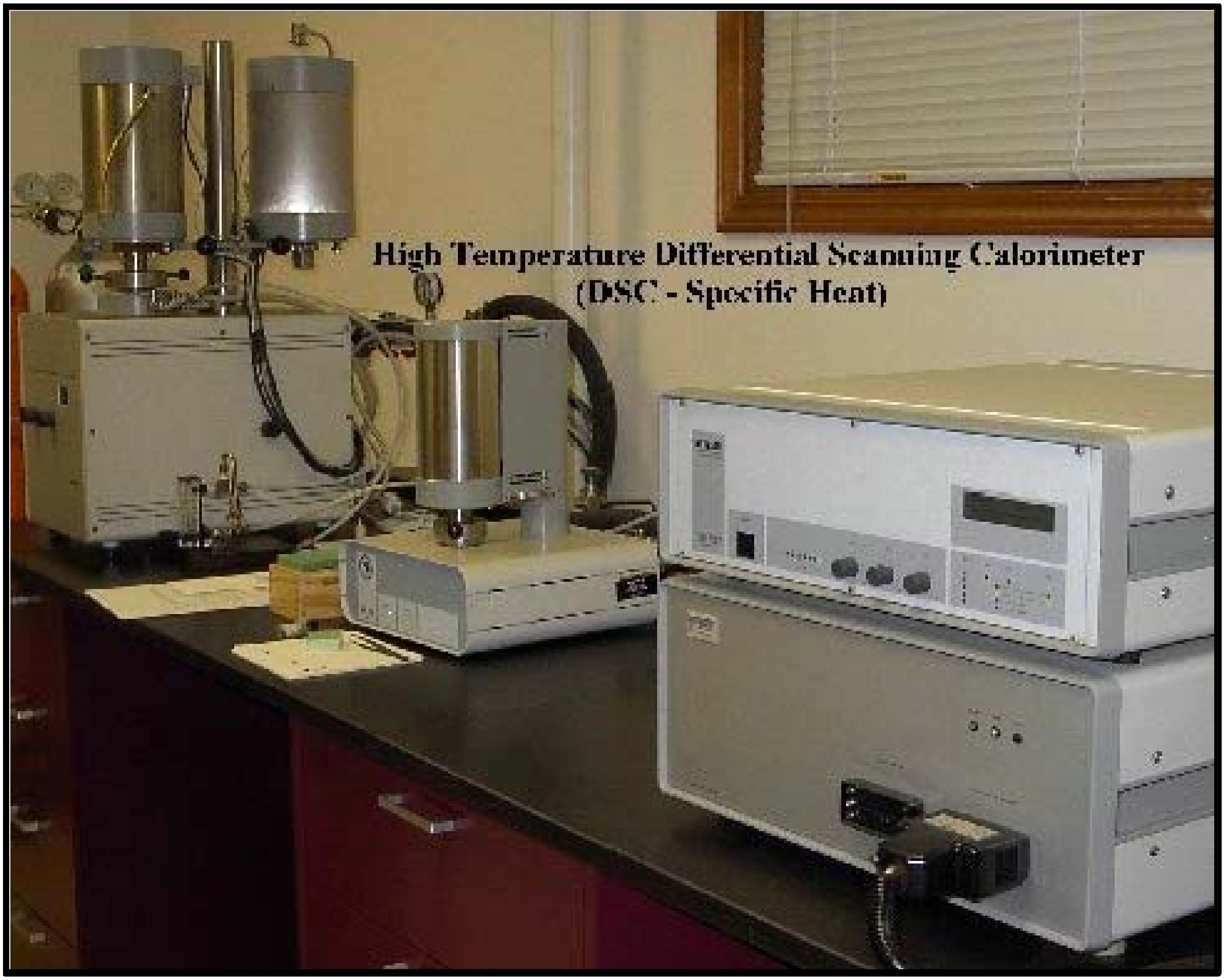


Figure 1 – Differential Scanning Calorimeter used for Measuring Specific Heat Properties of Multispectral Zinc Sulfide

Figure 2 – Push Rod Dilatometer used for Measuring Thermal Expansion Properties of Multispectral Zinc Sulfide

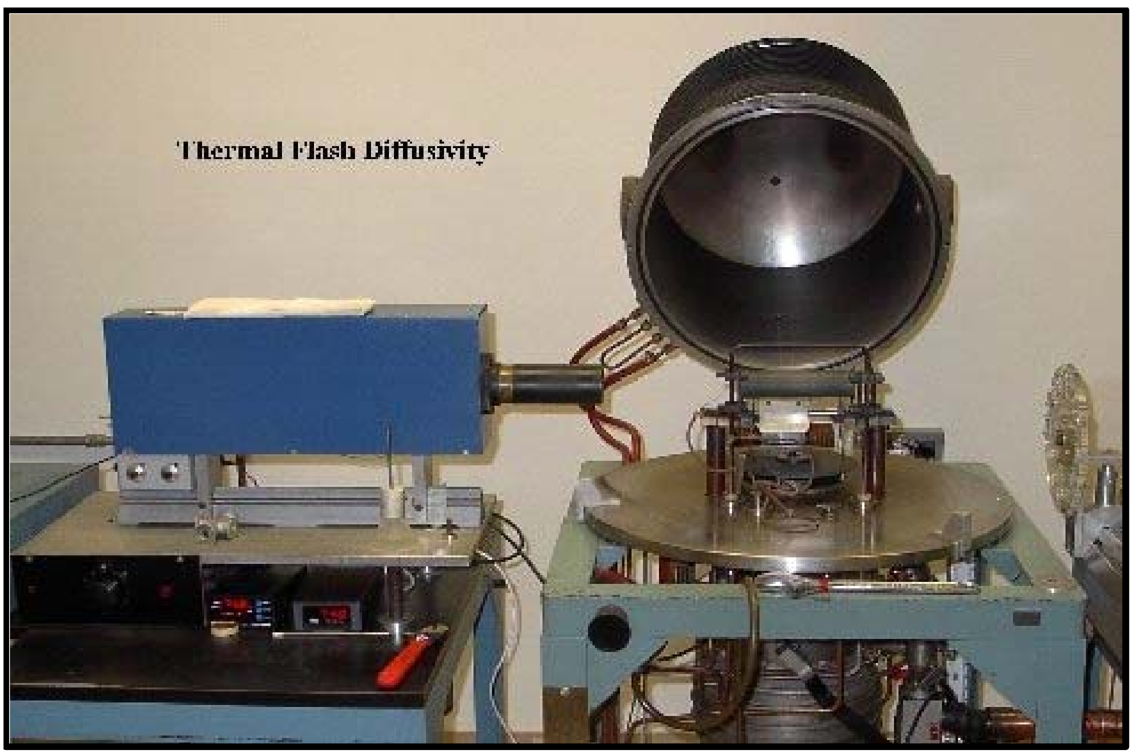


Figure 3- Laser Flash Diffusivity Equipment used to measure Diffusivity of Multispectral Zinc Sulfide

The plots of the thermophysical property data are shown in Figures 4-7. Note on these figures are the data/trends used for the analysis to select ZnS as an alternate seeker window material. Based on the test data shown as compared to the property data used for analysis, the probability of survival for ZnS remains valid.

Figure 4 – Plot of Specific Heat for Zinc Sulfide

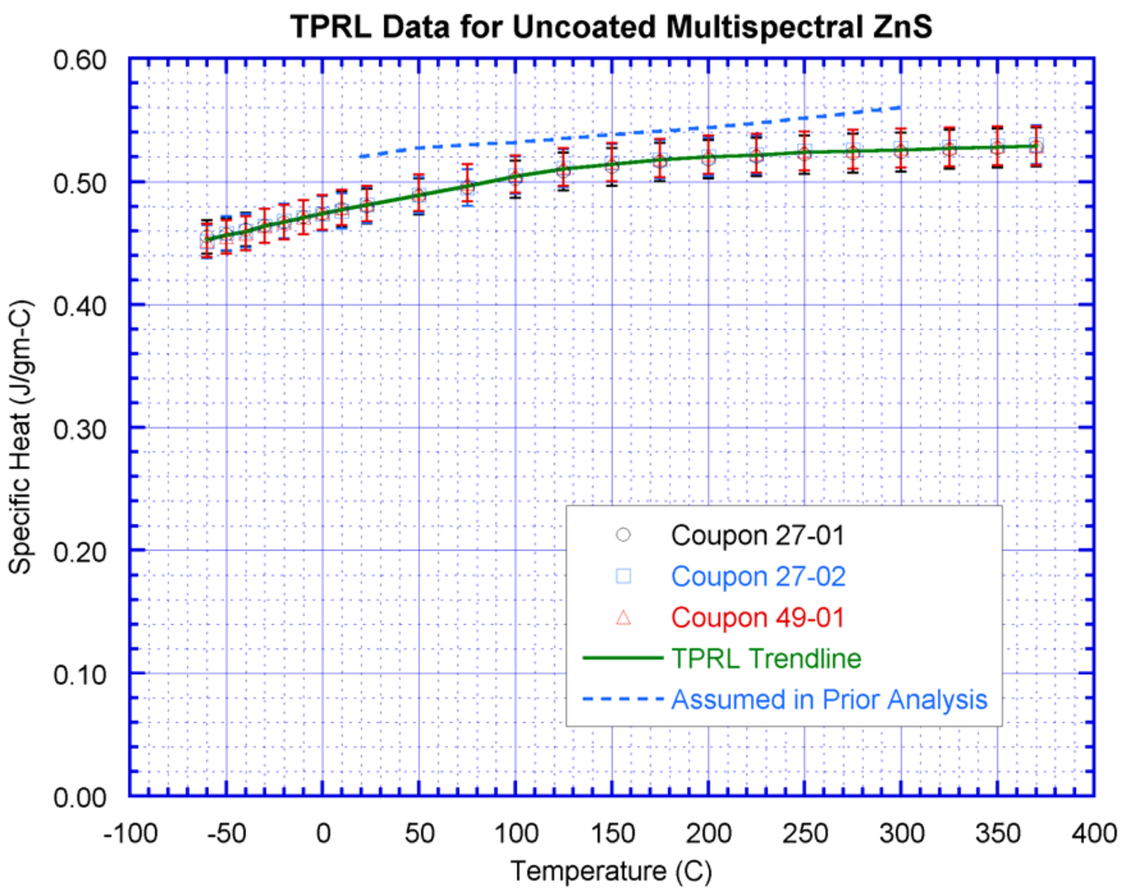


Figure 5 – Thermal Conductivity for Zinc Sulfide

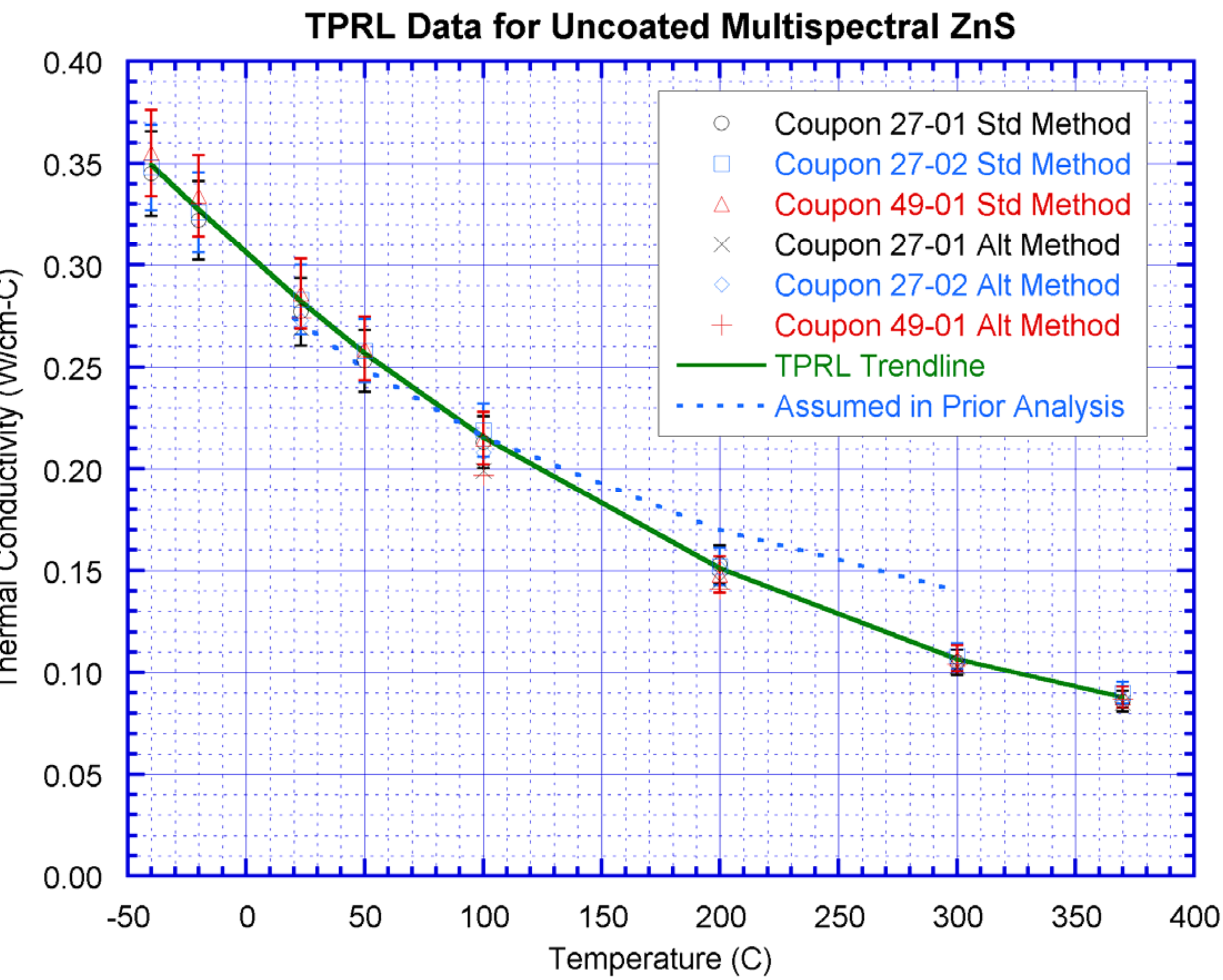


Figure 6 – Thermal Expansion Data for Zinc Sulfide

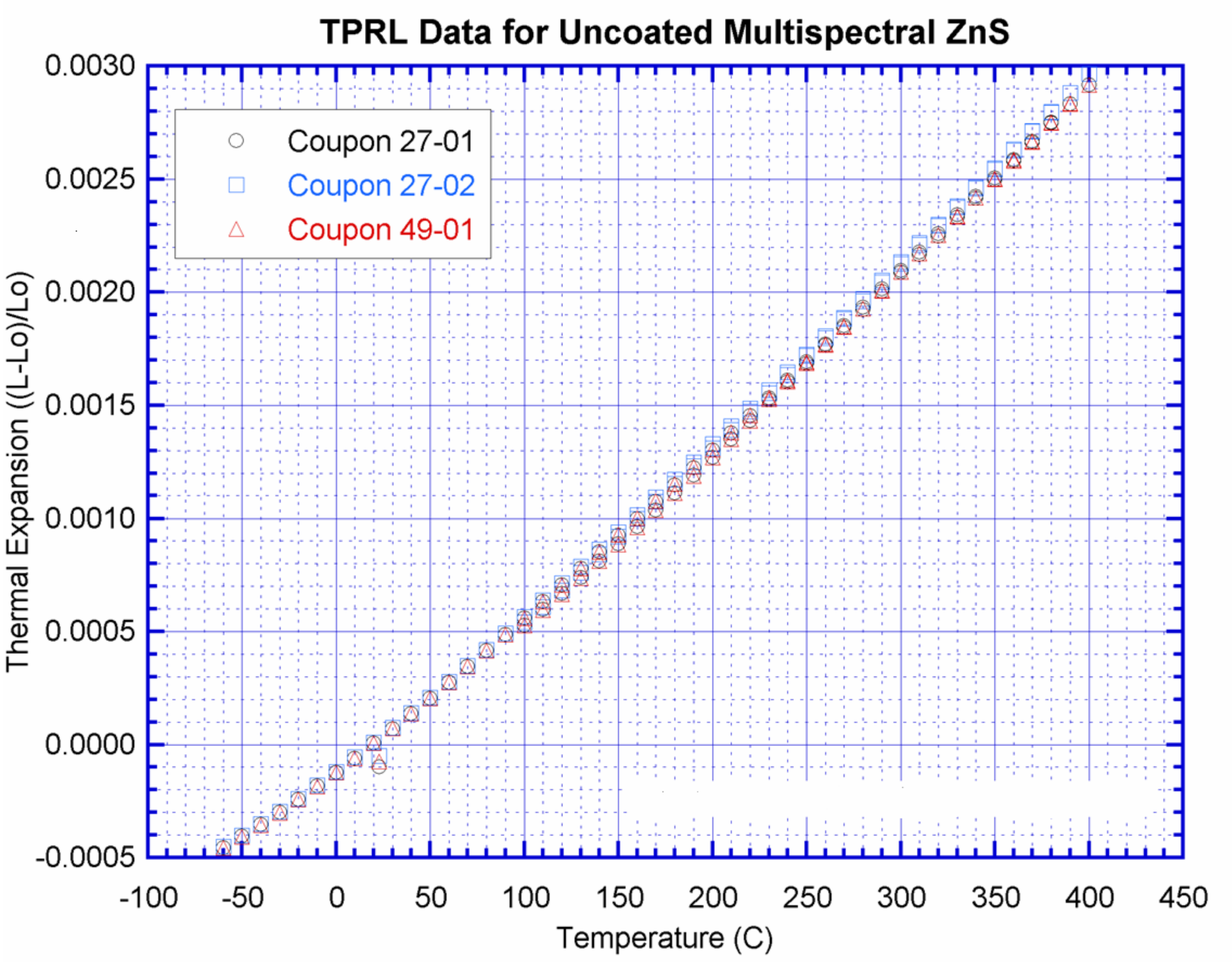
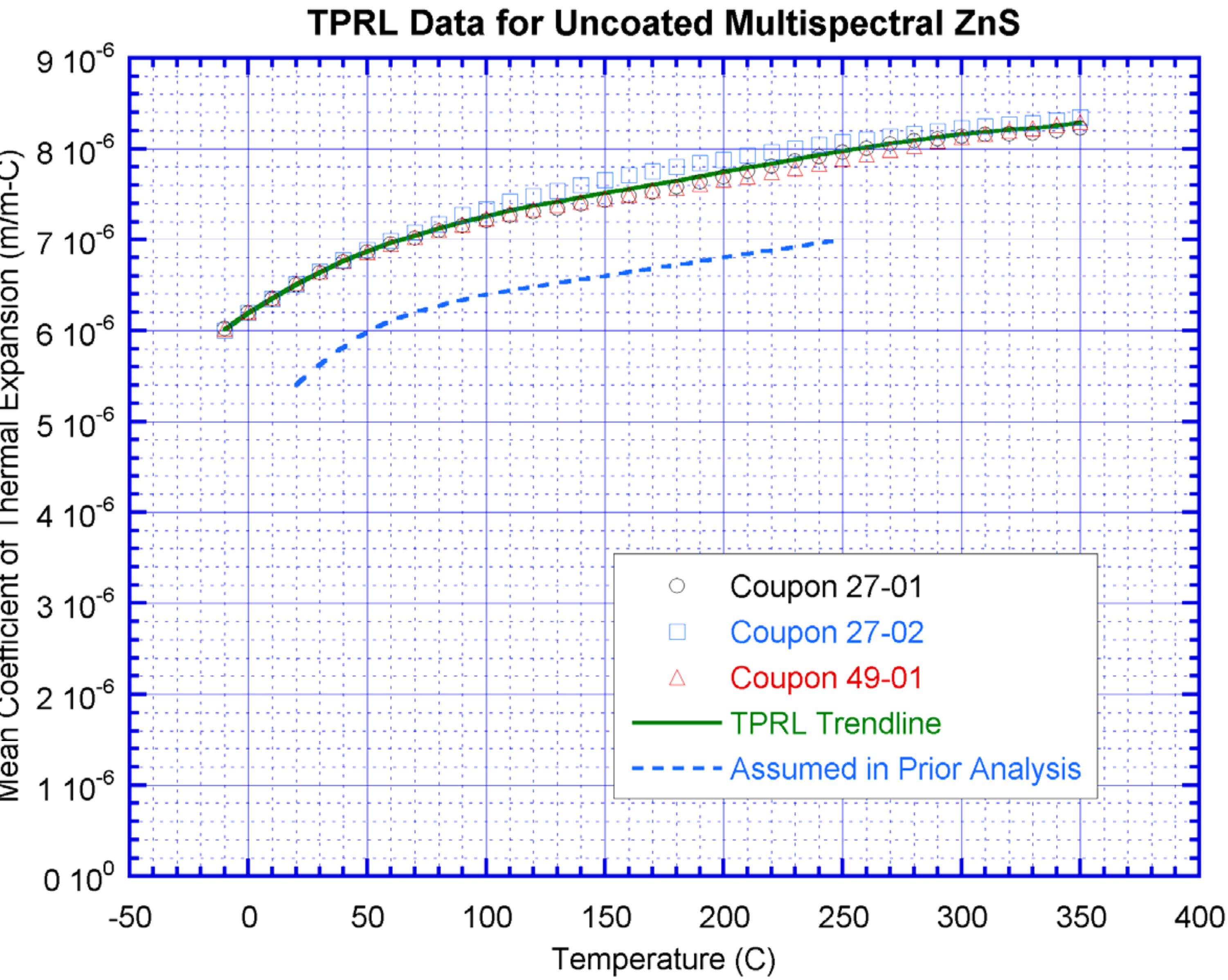


Figure 7 – Mean Coefficient of Thermal Expansion for Zinc Sulfide



When comparing the thermophysical properties to the predictions, the measured specific heat was 4-8% lower than the value used for analysis. This would lead to an approximately 6% increase in temperature rise. The analysis predicted a window surface temperature of 209°C and this will increase to nominally 220°C based on the test data. This increase does not present a concern since the optical properties are temperature insensitive (as shown in subsequent results) and the emissivity of the material was found to be very low.

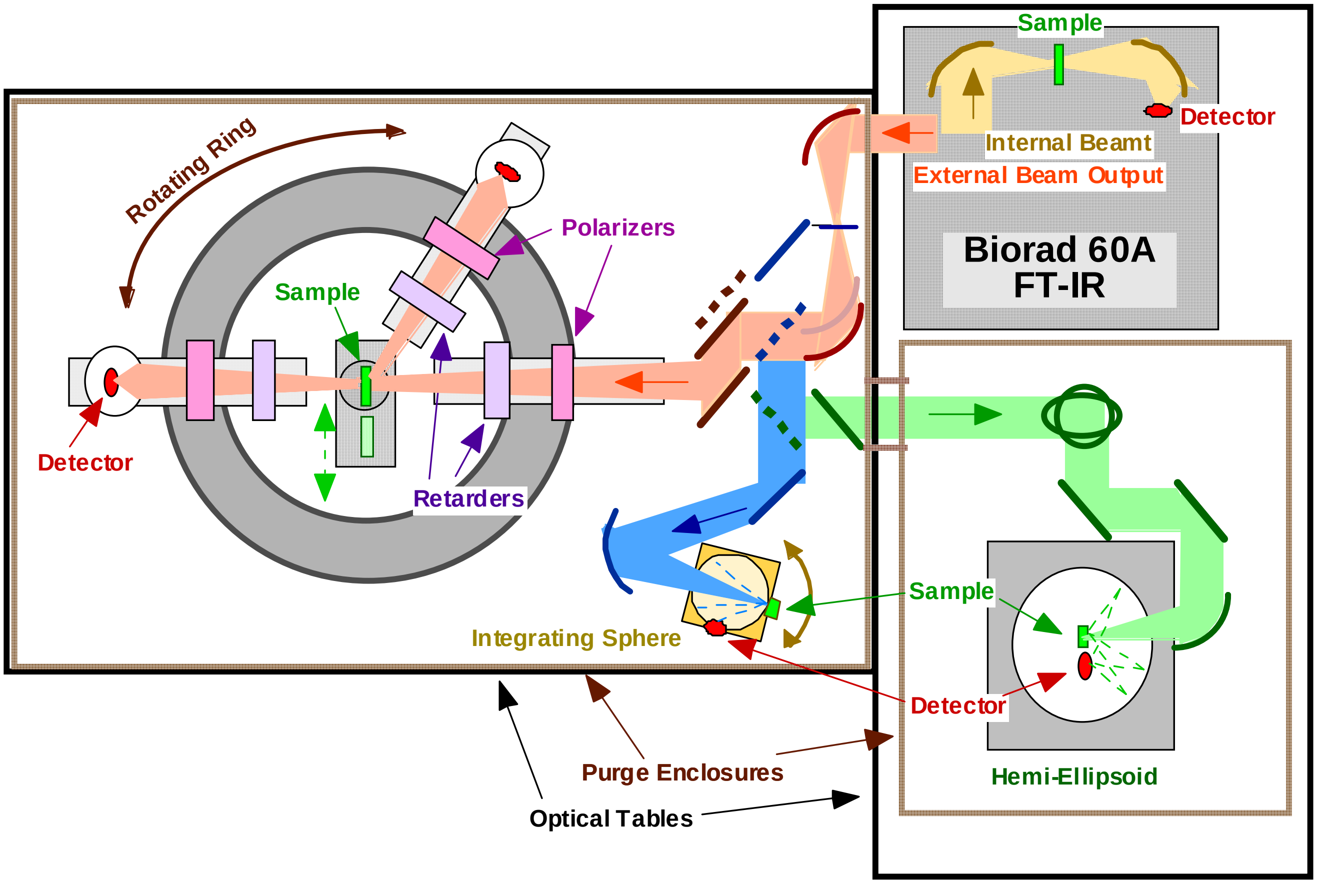
The thermal conductivity data used for analysis are comparable to the data for temperatures up to 150°C but was shown to be 12% lower at 200°C. As a result, near surface temperature gradients would increase for the worst case flight conditions. This is not a concern since peak stresses occur much earlier in flight where the window temperatures are in the temperature range where there was concurrence between the test data and that used for analysis.

The mean CTE data is nominally 12% higher than what was assumed and used in the analysis. This will result in higher stresses. However, this statement is based on the tensile strength capability of the material which was assumed prior to this testing. The predicted tensile strength was 9 MPa. Based on internal development efforts, the material is exhibiting a tensile strength of 68 MPa, a significant increase. The data scatter under these tests is very low which leads to a higher predicted structural reliability. The benefit of the increased structural strength combined with the low data scatter offsets the increase in stress due to higher thermal expansion.

The results of the optical property tests are shown below. The test matrix consisted of near normal transmission, reflection and emission of uncoated zinc sulfide. As discussed in section 1.0, 2 replicates were measured at 25, 200, and 250°C using a 3-11 micron spectrum. The test results for these tests are shown below. Note that in addition to these tests, transmission testing was also planned at RT and 200°C at incidence angles of 15, 30, 45, and 60 degrees.

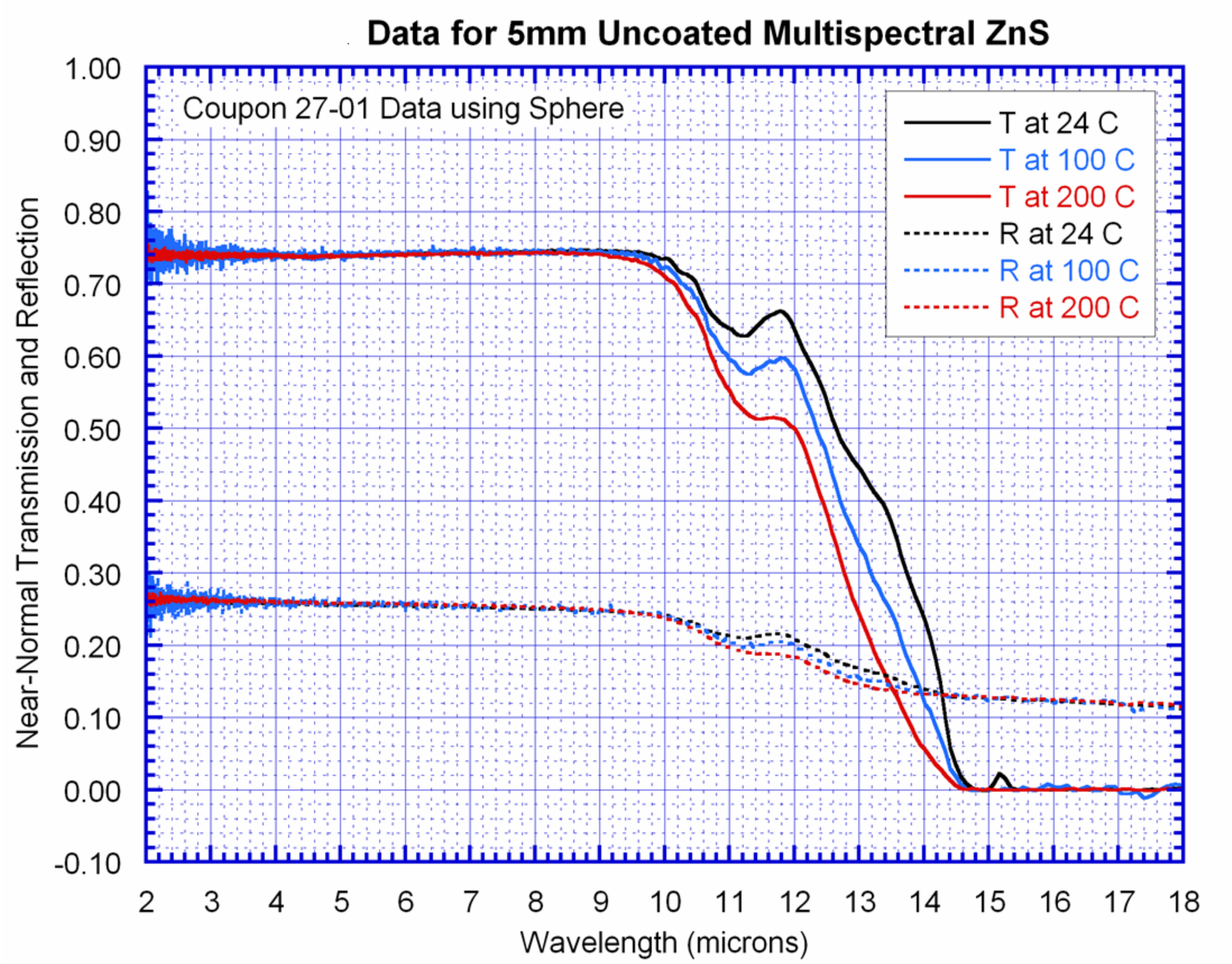
The optical testing was conducted using an IR spectrometer along with an integrating sphere and goniometer. A schematic of the test equipment is shown in Figure 8.

Figure 8 – Schematic Layout of Optical Testing of Zinc Sulfide



The results of the optical testing are shown on Figures 9-15.

Figure 9 - Near Normal Angle Transmission and Reflectance of Zinc Sulfide using a Cryostat Test Technique



Where: T = Transmission
R = Reflectance

Figure 10 - Near Normal Angle Transmission and Reflectance of Zinc Sulfide using a Sphere Test Technique

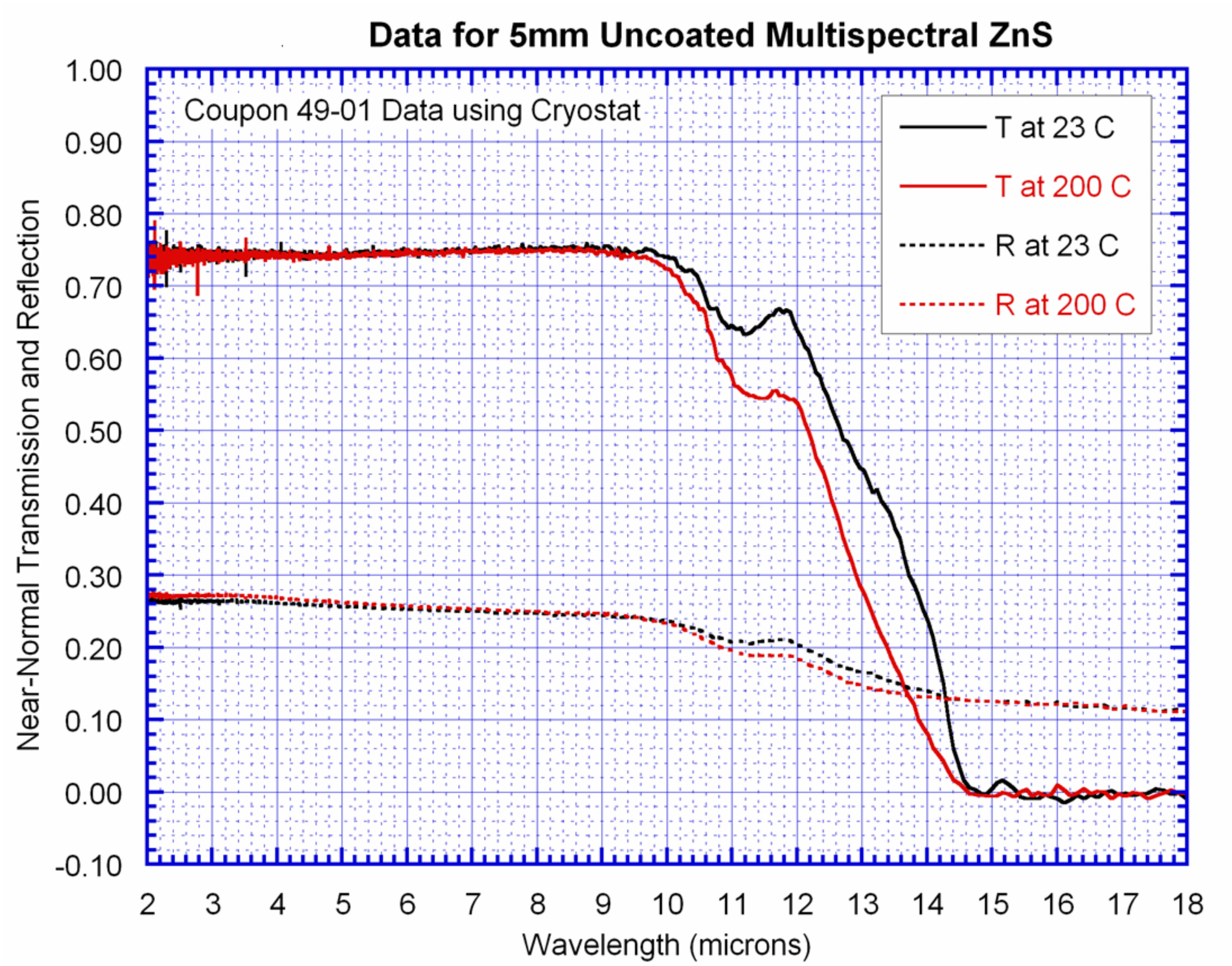


Figure 11 – Near Normal Angle Absorption/Emittance for Zinc Sulfide using a Sphere or Cryostat Test Technique

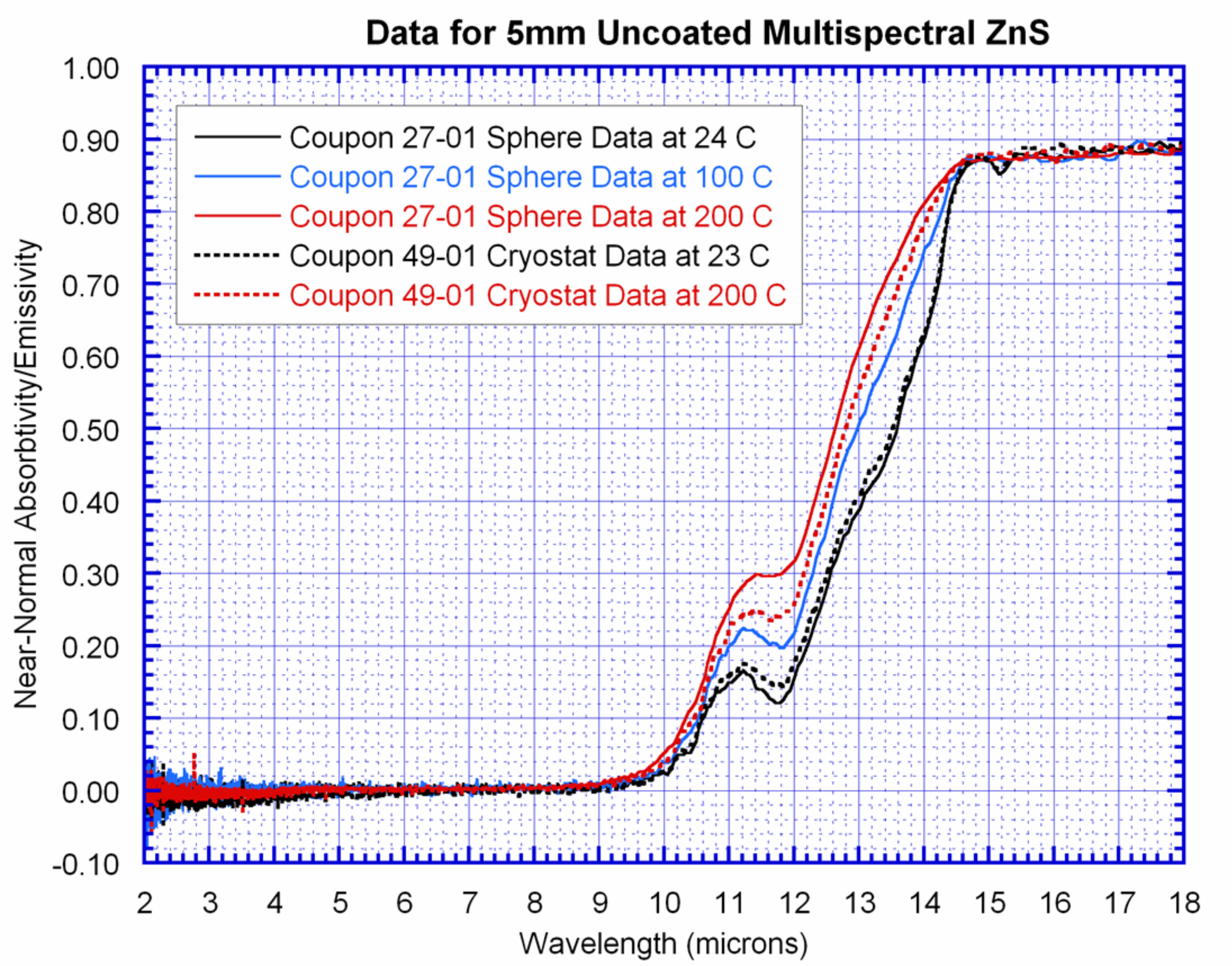

Data for 5mm Uncoated Multispectral ZnS
Coupon 27-01 Sphere Data at 24 C
Coupon 27-01 Sphere Data at 100 C
Coupon 27-01 Sphere Data at 200 C
Coupon 49-01 Cryostat Data at 23 C
Coupon 49-01 Cryostat Data at 200 C
Near-Normal Absorbtivity/Emissivity
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Wavelength (microns)

Figure 12 – Optical Transmission versus Wavelength for Varying Incidence Angles at Room Temperature for Zinc Sulfide using the Sphere Test Technique

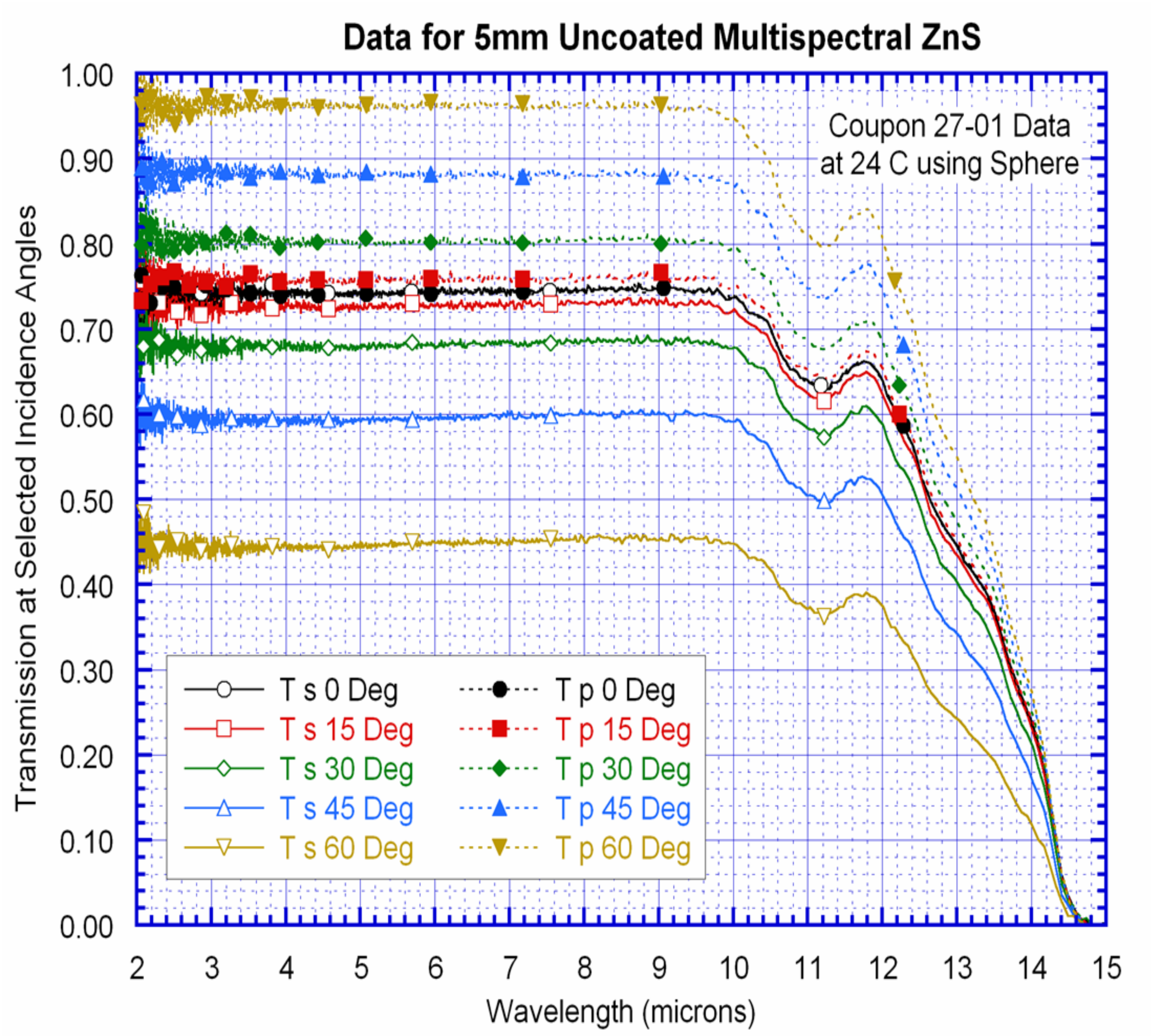


Figure 13 - Optical Transmission versus Wavelength for Varying Incidence Angles at Room Temperature for Zinc Sulfide using the Sphere Test Technique

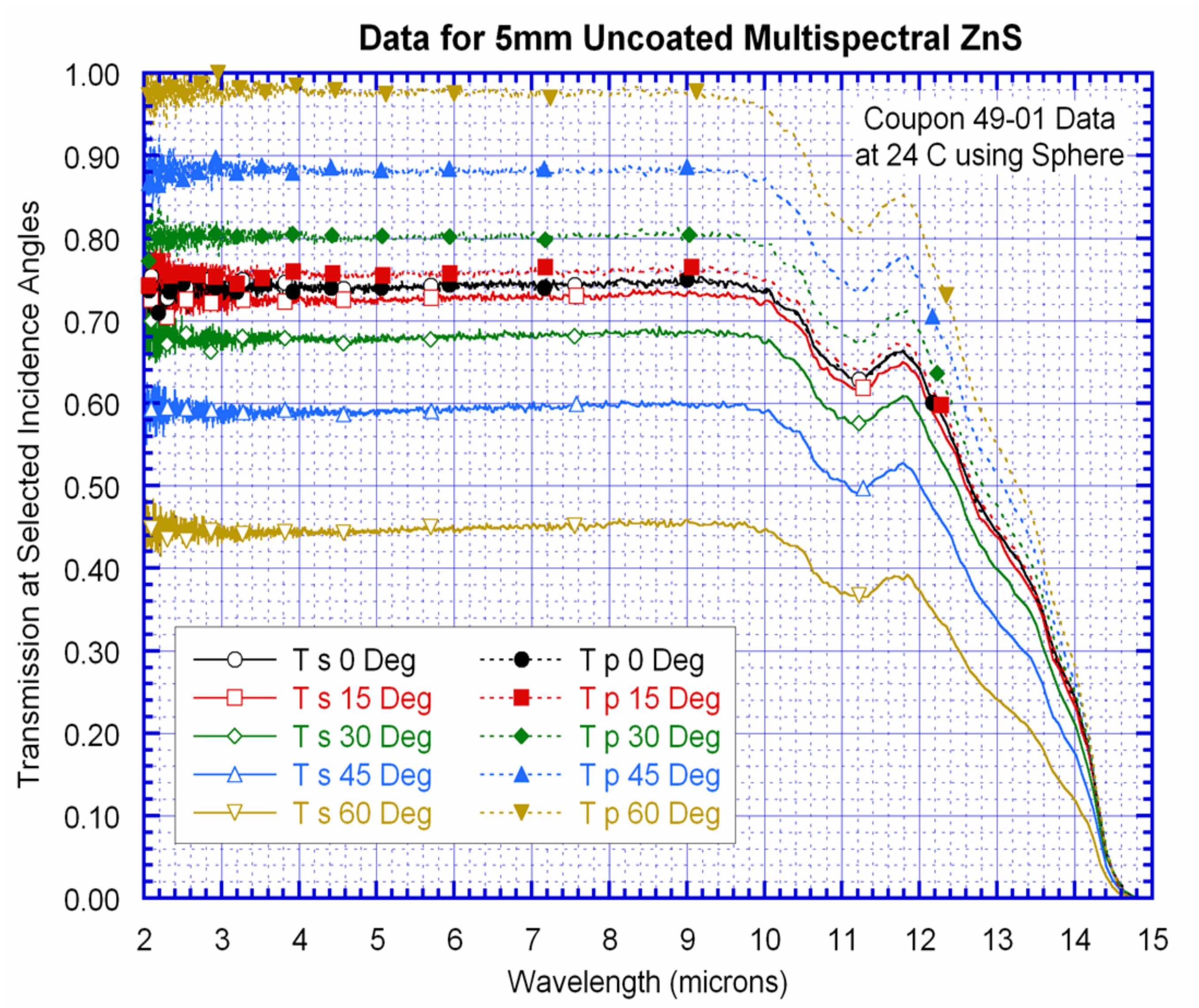


Figure 14 – Transmission versus Wavelength for Varying Incidence Angles for Zinc Sulfide using the Cryostat Test Technique

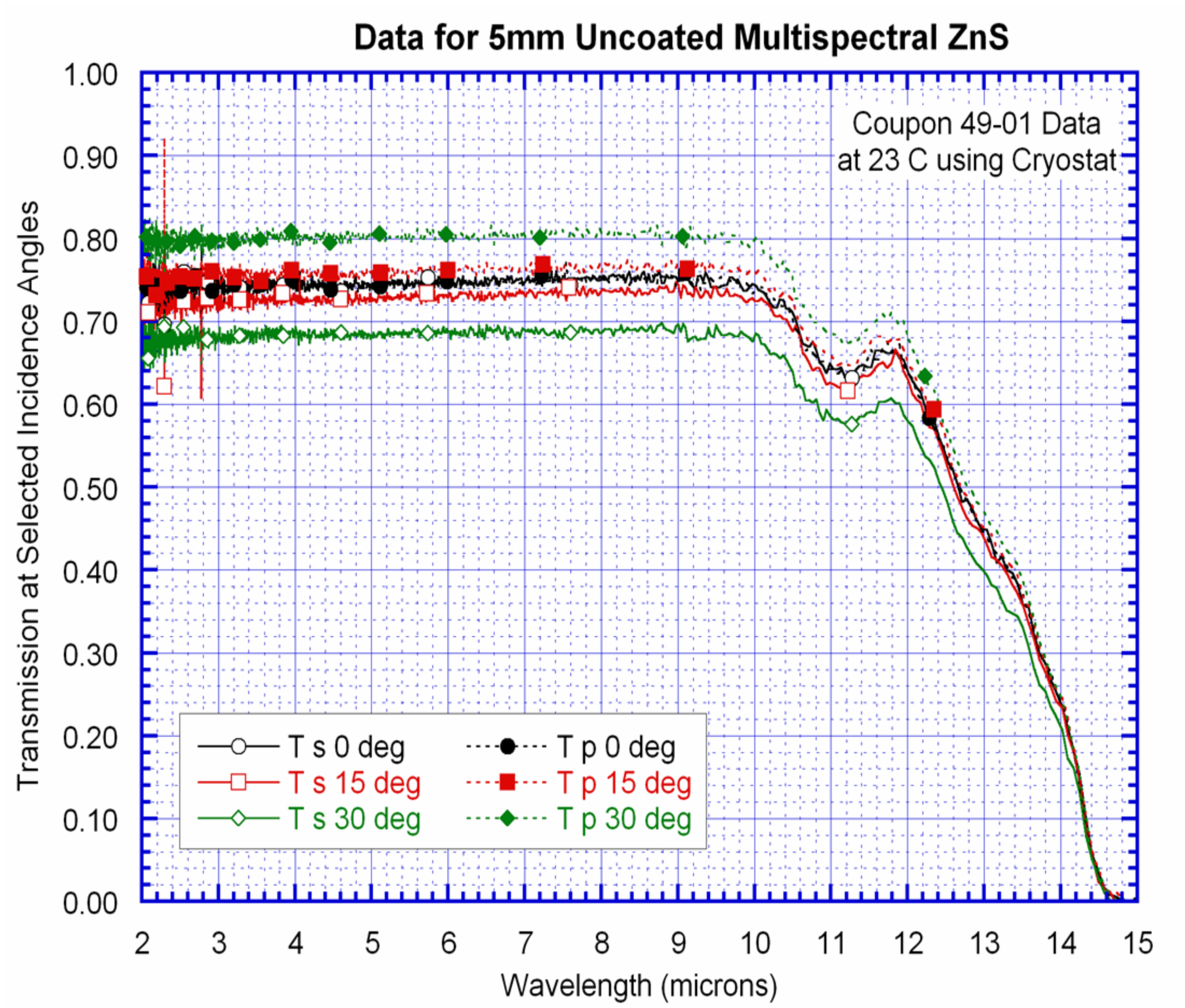
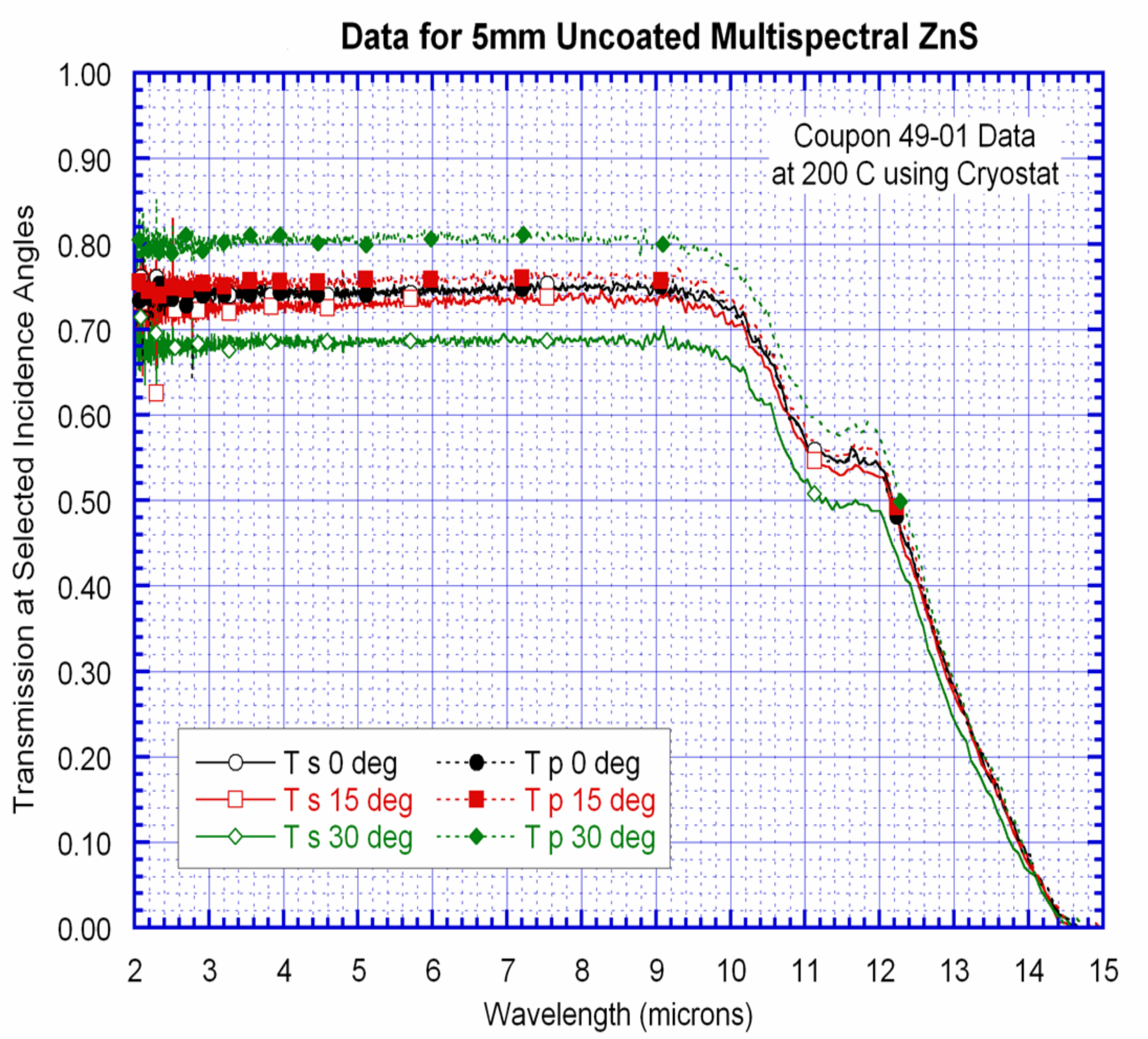


Figure 15 – Transmission versus Wavelength for Varying Incidence Angles for Zinc Sulfide using the Cryostat Test Technique



3.0 Conclusions

Based on the results obtained conducting thermophysical and optical property measurements, minor increases in window temperature and minor increased stresses are predicted during flight. The better than expected mechanical properties conducted under a separate effort more then compensate for the increased stress levels and the probability of survival for Zinc Sulfide remains greater than 99.9%. It is recommended that ZnS continue validation testing by demonstrating is thermostructural capabilities in a wind tunnel test.